CHAPTER 27

CAPACITIVE REACTANCE

Chapter 24 showed the different effects of inductance in a d.c. and an a.c. circuit. Inductance only effects a circuit while there is a changing magnetic field. In a d.c. inductive circuit, the only opposition to a steady state current is the resistance of the circuit. In the capacitive d.c. circuit, there is no steady state current as the current decreases to zero when the capacitor is fully charged. In an inductive a.c. circuit, a property called inductive reactance existed in the circuit while current through the inductor changed. As there is no current in a capacitor, what would a student expect to happen when the capacitor is connected to an alternating current supply?

27.1 ELECTRON MOVEMENT IN DIELECTRICS

When a d.c. voltage is applied to a capacitor and the capacitor becomes charged the orbits of the electrons around their nuclei are distorted. (Figure 27.1).

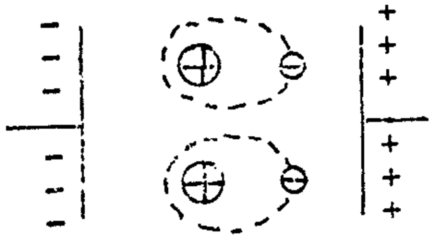


Figure 27.1

If the polarities applied to the capacitor are reversed the electron orbit will distend in the opposite direction. (Figure 27.2).

While there is no actual movement of electrons between the plates of a capacitor there is movement of the electrons within the orbits in the dielectric (Figure 27.2).

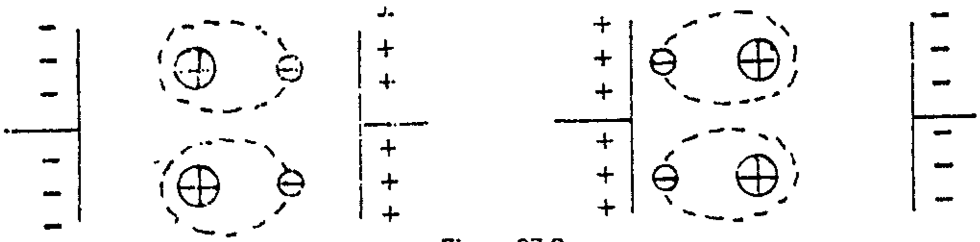


Figure 27.2

When a capacitor is connected to an alternating current voltage the reactions that occur in figure 27.2 are proceeding continuously.

27.2 CAPACITIVE REACTANCE

If the resistance of the connecting wires of a circuit consisting of a capacitor and an a.c. supply is ignored, the only opposition to current is the charging and discharging of the capacitor, or the changing of the orbits of the electrons in the dielectric. The changing of the electron orbits is a reaction due to the continuous reversal of the polarities of the alternating current. This reaction, or opposition, to alternating current is known as capacitive reactance (symbol X_c), and because it is opposition to electrical current its units are ohms. Increasing the capacitance of the capacitor and/or the frequency of the a.c. supply decreases the opposition to the charging and discharging current.

$$X_c \propto \frac{1}{f\ C}$$

As the reactions occur over one cycle or 2π radians, the capacitive reactance of a capacitor is calculated from the equation:-

$$X_c = \frac{1}{2\pi f C} \text{ ohms}$$

Where

X_c = capacitive reactance in ohms

f = frequency of the a.c. supply in hertz

c = capacitance in farads

Example 27.1

Calculate the capacitive reactance of a capacitor of 20 F that is connected to a 50 Hz supply.

C = 20 F

f = 50 Hz

X_C = ? Ω

$$X_C = \frac{1}{2 \pi f C}$$

$$= \frac{1}{2 \pi \times 50 \times 20}$$

$$= 0.000159 \, \Omega$$

As stated earlier a capacitor that has a capacitance in farads is difficult to produce. However electrolytic capacitors are being evolved which are closing the gap between the microfarad and farad range. Using the existing capacitors available the equation for capacitive reactance becomes:-

$$X_c = \frac{1}{2 \pi f C \times 10^{-6}} \text{ ohms}$$

$$= \frac{10^6}{2 \pi f C} \text{ ohms}$$

Where C is in microfarads

Example 27.2

A 50 μF capacitor is supplied from a 100 Hz source. Calculate its capacitive reactance.

C = 50 μF

f = 100 Hz

X_c = ? Ω

$$X_c = \frac{10^6}{2 \pi f C}$$

$$= \frac{10^6}{2 \pi \times 100 \times 50}$$

$$= 31.8 \, \Omega$$

27.3 CAPACITIVE CURRENT

When a continuously changing voltage of alternating current is applied to a capacitor, the capacitor voltage will follow the same pattern, the voltage E_c being of the same waveform and magnitude as the supply volts. (Figure 27.3).

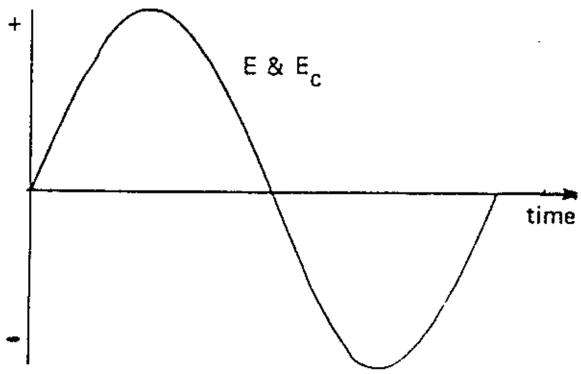


Figure 27.3

Capacitive reactance opposes current flow, so the method of determining the current in this type of circuit is the same as in other circuits.

For purely resistive a.c. circuits —

$$I = \frac{E}{R} \text{ amperes}$$

For purely inductive a.c. circuits —

$$I = \frac{E}{X_L} \text{ amperes}$$

For purely capacitive a.c. circuits —

$$I = \frac{E}{X_c} \text{ amperes}$$

Example 27.3

A capacitor of 50 microfarads is supplied from a 240 volt 50 hertz source. Calculate —

(a) the capacitive reactance of the capacitor

(b) the current drawn from the supply by the capacitor

$C = 50\ \mu F$

$f = 50$ Hz

$E = 240$ V

$X_C = ?$ ohms

$I = ?$ A

$$X_c = \frac{10^6}{2 \pi f C}$$

$$= \frac{10^6}{2 \times \pi \times 50 \times 50}$$

$$= 63.7\ \Omega$$

$$I = \frac{E}{X_c}$$

$$= \frac{240}{63.7}$$

$$= 3.77 \text{ A}$$

Example 27.4

Connecting a capacitor to a 240 volt 50 Hz supply causes a current of 2 amperes to be drawn from the supply. Calculate the capacitance of the capacitor.

$E = 240$ V

$I = 2$A

$f = 50$ Hz

$C = ?\ \mu F$

$$X_c = \frac{E}{I}$$

$$= \frac{240}{2}$$

$$= 120\ \Omega$$

$$X_c = \frac{10^6}{2 \pi f C}$$

$$C = \frac{10^6}{2 \pi f X_c}$$

$$= \frac{10^6}{2 \pi \times 50 \times 120}$$

$$= 26.5\ \mu F$$

27.4 RELATIONSHIP BETWEEN VOLTAGE AND CURRENT in a purely capacitive circuit.

As stated previously, when the voltage across a capacitor is a maximum the current in a capacitive circuit is zero. This short circuiting effect of an uncharged capacitor causes the current in a capacitive a.c. circuit to lead the voltage by 90 electrical degrees. (Figure 27.4).

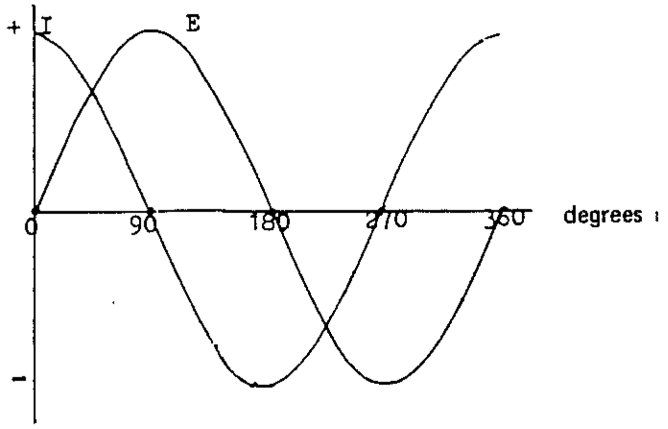


Figure 27.4

As there is no electron movement through the capacitor there will be no power loss in the capacitor during the charging and discharging cycles.

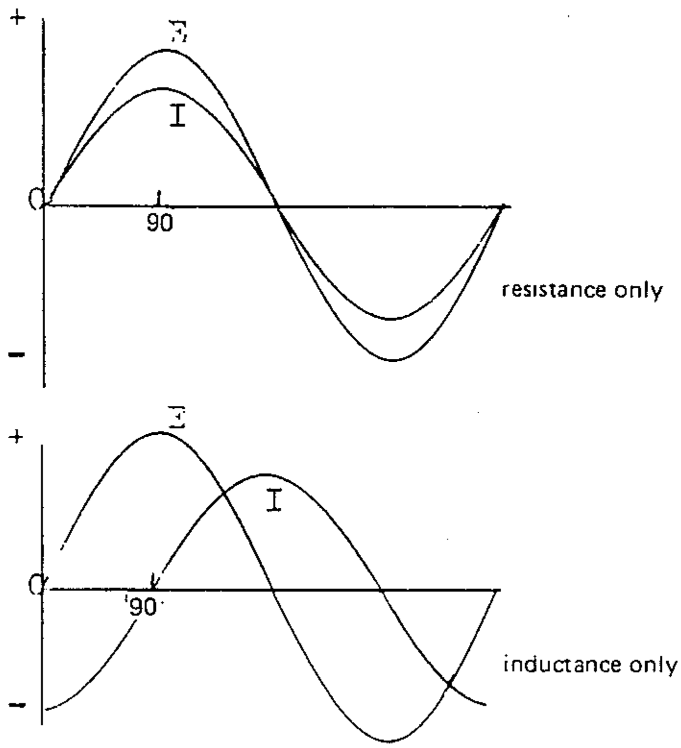
27.5 SUMMARY OF THE CURRENTS IN A PURELY RESISTIVE, INDUCTIVE AND CAPACITIVE a.c. CIRCUIT

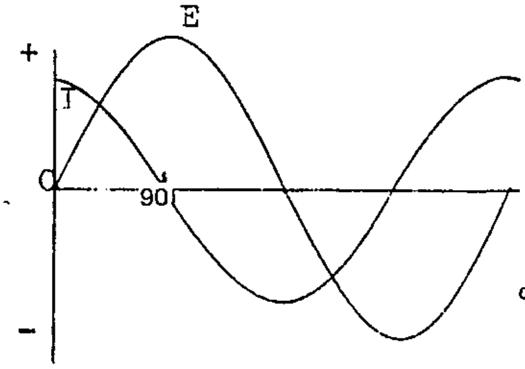
For comparison purposes the voltages and currents in an a.c. circuit containing only one component are shown in figure 27.5.

In a purely resistive circuit the current reaches its maximum value at the same time as the voltage. The two waves are said to be 'in phase' with each other.

In a purely inductive circuit the current reaches its maximum 90^{o} after the voltage reaches its maximum. The current is said to **lag** the voltage by an angle of 90^{o}.

Lastly, in a purely capacitive circuit the current leads the voltage by 90^{o} (previous explanation).





capacitance only

Figure 27.5

Equations in this chapter

(1) $X_c = \frac{E}{I}$

(2) $X_C = \frac{10^6}{2 \pi f C}$

TUTORIALS 1.27

(1) Calculate the capacitive reactance of a 15 μF capacitor that is connected to a 50 Hz supply.

(2) The capacitive reactance of a capacitor is 50 Ω when it is supplied from a 50 Hz source. Calculate the capacitance of the capacitor.

(3) Calculate the current drawn from a 240 V 50 Hz supply by a 75 μF capacitor.

(4) A capacitor draws 5 amperes from a 240 V 50 Hz supply. Calculate its capacitance.

(5) Calculate the frequency that would produce a capacitive reactance of 25 Ω in a 50 μF capacitor.